a W. wind prevailed. This NNW. wind was considerably stratified as regards temperature, there being a cold stratum at 750 m. (−4.0° C.) above which temperature rose to a maximum of 2.8° C. at 2,000 m.; then followed a rather sharp fall as the wind backed to W.

At Broken Arrow on the 8th the winds up to 3,000 m. conform both as to direction and clockwise turning with those of Groesbeck. On the succeeding day they were more northerly than at Groesbeck.

The temperature of the free air at Broken Arrow on the 8th shows a weak minimum at the 500 m. level, and a distinct rise from that level to a maximum at 1,250 m.; thence to the top of the flight the temperature fell 13.3° C. in 2,250 m.—a not unusual fall in temperature—in southerly winds. On the following day with northerly winds the air column was uniformly colder, as would be expected, although the difference at the 3,000-m. level was but 4.5° C.

On March 9 (see fig. 2) the center of the cyclone was apparently off the mouth of the Mississippi, although its position is dependent upon the single barometer reading of New Orleans, La. It is evident that there was not a movement of translation from New Mexico on the 8th to the Gulf of Mexico on the 9th, but rather that a new cyclone developed in the southern end of the barometric trough that is present in Figure 1, paralleling the Rio Grande Valley. (See the isobar of 29.80 inches.)

Consider now the observations made at Due West, S. C., which on the 9th was in relatively the same position with respect to the cyclone center as Groesbeck and Broken Arrow were on the previous day. The free-air winds at due West were from an easterly quarter with the same clockwise turning through S. to SW. as obtained at the two stations first discussed. The high clouds at this station, as also in Texas and Oklahoma, were moving from a southerly quarter. (See footnotes of Table 1.)

A small inversion of temperature is apparent at Due West between surface and 750 m. and a steady decrease from that level to the top of the flight. The decrease between 2,000 and 2,500 m. as the winds shift from SSE. to S. is rather pronounced.

The precipitation at Royal Center, Ind., owing to the high latitude of the station, was in the form of snow rather than rain. Easterly winds with a snowstorm prevailed at that station and the flight was not a high one.

The clockwise shift of the wind at Royal Center suggests that at that station, although at a great distance from the cyclone center the winds at higher elevations than those recorded must have been from a southerly quarter.

The barometric situation on the 8th and 9th compared.—The outstanding feature of the map of the 8th (fig. 1) is the ridge of high pressure that extends from Canada southeastward to Florida and the accompanying thrust of cold northwest winds. This ridge lying athwart the path of the New Mexico cyclone threatens the existence of the latter. Apparently, however, the danger to the New Mexico cyclone was not in the eastern ridge of high pressure but in the more direct and vigorous thrust of cold northerly air in its rear which reached the Gulf of Mexico by the morning of the 9th. The situation is now completely changed and the conditions for very generous and widespread precipitation in the great central valleys and Atlantic Coast States are almost ideal, viz, a trough of low pressure between two ridges of high pressure. From its position on the 9th the cyclone advanced northeastward, reaching the Delaware Capes on the 11th as a circular depression with central pressure of

29.00 inches. Heavy snow for the season fell in the Middle Atlantic and New England States.

The data here presented, and other evidence of a similar character, seem to indicate that for the continent of North America, at least, the southerly winds on the front of the cyclone, generally much stratified as to temperature, and the northerly winds in its rear, less stratified than those first mentioned, are the two most impressive phenomena in connection with cyclonic activity. These two major currents are not to be considered as opposing currents, but rather as currents one of which regularly supplants the other in practically the same levels.

The time required for the completion of the cycle warm–cold is short, a day or so, and it evidently bears a direct relation to the cycle, cyclone–anticyclone, which of course varies with the season and the latitude.

Each system of warm southerly winds must, of course, have two border zones, one on the left and one on the right as one faces toward the south. The movement of the air in the vertical on the right margin is pretty clearly established as an underrunning of the warm by the cold northerly current. The movement in the vertical on the left margin is not so clearly indicated; in the opinion of the writer the locus of cyclonic activity will be found nearer the left margin than the right.

In some respects these two wind systems, as conceived by the writer, are similar to the warm and cold currents postulated by the Norwegian school of meteorologists, although the details differ in several particulars. The generous cooperation of the Aerological Division of the bureau in the preparation of this paper is gratefully acknowledged.

551.578.4 (775)

THE SLEET, GLAZE, SNOW, AND WINDSTORM IN WISCONSIN, FEBRUARY 3–6, 1924

By W. P. STEWART, Meteorologist

(Weather Bureau, Milwaukee, Wis., March 29, 1924)

This storm occurred in connection with a marked area of low pressure which came up the Mississippi Valley on February 3 and 4 and passed slowly northeastward over Illinois, Indiana, and Michigan on the 5th and 6th. Southern and eastern Wisconsin were within the area of precipitation from February 3 until the morning of the 7th, and during that period heavy snows occurred over the greater part of this section. It was heaviest near Lake Michigan. At Milwaukee the heaviest 24-hour snowfall of record, 20.3 inches, occurred on the 4th–5th, and the total fall in the storm was 22 inches. At Manitowoc there was 25.5 inches, at Sheboygan 18 inches, at Port Washington 16 inches, at Racine 17 inches, at Sturgeon Bay 15 inches, and over a large part of central and southern Wisconsin the fall was from 10 to 12 inches.

There was a high east and northeast wind on the 3d, 4th, and 5th, and the snow drifted badly. Railway and interurban traffic was delayed 1 to 3 days. The most serious interruption to train service occurred in the territory north of Milwaukee, on the routes along the lake shore and in the vicinity of Fond du Lac and Oshkosh, where the schedules were interrupted from the night of the 4th until the afternoon of the 6th, and service was not fully restored until the 8th. Between Milwaukee and Chicago the service was interrupted from 9 p. m. the 4th until the afternoon of the 5th.

There were many miles of snowdrifts 8 to 12 feet high and highway traffic was blocked generally throughout the

area affected. This condition improved very slowly; some highways were not opened to traffic until the end of February. In the vicinity of Sheboygan automobiles were not able to get through until the last week in March.

The interests most seriously affected by the storm, however, were the overhead wire companies. In southern and southeastern Wisconsin the precipitation began on February 3 as a light misting rain which turned to sleet and snow during the night, the temperature being slightly below the freezing point. All exposed objects were covered with glaze. In Milwaukee the coating of ice averaged about $\frac{3}{16}$ inch in thickness, but the telegraph and telephone companies report that at some other points the coating of ice on wires was $\frac{1}{2}$ to $\frac{3}{4}$ inch in diameter. This ice together with the high winds caused the breakage of large numbers of telegraph and telephone poles and the prostration of many miles of wire. One company alone reported 924 poles broken, 480 miles of wire destroyed, 11,000 wire breaks, and 3,800 miles of wire to be repulled and retied to insulators. Their monetary loss was $172,000.

Because of broken wires, etc., the toll-line circuits of the telephone companies began to fail soon after midnight February 3–4, and most of them were out of order by 7 a. m. the 4th. Over most of these lines service was restored by the afternoon of the 9th, but in several localities it was interrupted for 10 days, and one of the larger companies expected that permanent repairs would not be completed until May 1.

From all available data it is estimated that the actual property loss from the storm was approximately $231,000, but the economic loss from delayed traffic of all kinds was much greater.

TORNADO IN NORTH TEXAS ON APRIL 3, 1924 [1]

A tornado was observed in Denton County, Tex., near the village of Justin about 4 p. m. April 3, 1924. It moved thence in an east-southeast direction through the northeast corner of Dallas County, the northern end of the adjoining county of Kaufman and was last observed about a mile southwest of Edgewood in Van Zandt County, having traveled a distance of about 80 miles in four hours. The tornado passed over a thinly settled district and for a part of its course the funnel cloud was not in direct connection with the ground. One person was killed and 14 injured and property loss of about $40,000 was sustained.

The meteorological conditions at the Dallas Weather Bureau station, when the tornado passed to the eastward about 12 miles directly north of the station, were not unusual or striking in any respect. The barometer fell from 29.88 inches at 8 a. m. 75th meridian time to 29.72 inches at 5:45 p. m. and then rose sharply 0.03 inch.

Hail fell in the path of the tornado in Denton, Rockwall, and Dallas Counties. There was but little thunder and lightning. The width of the tornado's path was about 1,000 feet and that of the hail fall from $\frac{1}{2}$ to 2 miles.

The usual number of freaks, such as straws being driven into wood, etc., were observed.

[1] Condensed from a report by J. L. Cline, Meteorologist, Weather Bureau Office, Dallas, Tex.

NOTE ON PARTIAL CORRELATION [1]

551.501   By EDGAR W. WOOLARD

At the time that Doctor Walker commenced his researches on seasonal correlations [2], the modern form of the theory of multiple linear correlation was new [3], and in large part he developed his own notation and methods. Walker's method of deriving the total correlation coefficient and the regression equation differs from that expounded in the textbooks of statistics, yet it apparently entails less arithmetical labor, and should be more widely known than it is.

If a variable quantity X_1 depends upon a number of other variable quantities $X_2, X_3, \ldots X_k$, then we may look upon the successive variations of X_1 from its arithmetic mean as made up of (1) portions due to the variations of X_2 from its arithmetic mean, and (2) remainders, independent of X_2, due to the variations in $X_3, \ldots X_k$, and more or less of the nature of accidental errors. Under these circumstances, if we assume a linear relation between the variations x_1 from the mean of X_1 and the variations x_2 from the mean of X_2, the Theory of Least Squares gives for the "best" representation of the relationship.

$$x_1 = r\frac{\sigma_1}{\sigma_2}x_2 \qquad (1)$$

in which the so-called correlation coefficient

$$r = \frac{\Sigma(x_1 x_2)}{N\sigma_1\sigma_2} \qquad (2)$$

expresses the proportionate extent to which the variations in X_1 are determined by, or related to, those of X_2. Similarly, if we wish to determine the extent to which the variations in X_1 are due to those in $X_2, X_3, \cdots X_n$ jointly, exclusive of the effects of $X_{n+1}, X_{n+2}, \cdots$, we have, assuming a linear relation

$$x_1 = a_{12}x_2 + a_{13}x_3 + \cdots + a_{1n}x_n, \qquad (3)$$

where, in the case of four variables for example, as Walker has shown

$$a_{12} = \frac{\sigma_1\{r_{12}(1 - r^2_{34}) + r_{13}(r_{24}r_{34} - r_{23}) + r_{14}(r_{23}r_{34} - r_{24})\}}{\sigma_2\{1 - r^2_{23} - r^2_{24} - r^2_{34} + 2r_{23}r_{34}r_{34}\}}, \text{etc.,} \quad (4)$$

while the "effective correlation coefficient" is

$$m = \frac{1}{\sigma_1}\sqrt{[a_{12}\sigma_2 r_{12}\sigma_1 + a_{13}\sigma_3 r_{13}\sigma_1 + a_{14}\sigma_4 r_{14}\sigma_1]}, \qquad (5)$$

and expresses the proportionate extent to which the variations in X_1 are governed by those in X_2, X_3, X_4.

[1] Presented as part of the discussion on Dr. G. T. Walker's method of making monsoon rain forecasts, Weather Bureau staff meeting of Apr. 16, 1924.

[2] G. T. Walker. Correlations in Seasonal Variations of Climate, *Mem. Ind. Metl. Dept.*, Vol. XX, pt. 6, 1909; Correlation in Seasonal Variations of Weather, II, *Mem. Ind. Metl. Dept.*, XXI, pt. 2, 1910; III, XXI, 9, 1914; IV, XXI, 10, 1915; V, XXI, 11, 1915; VI, XXI, 12, 1915; VII, XXIII, 2, 1922; VIII, XXIV, 4, 1923.

[3] G. U. Yule. On the Theory of Correlation for any Number of Variables, Treated by a new System of Notation. *Proc. Roy. Soc.*, A79, 182–193, 1907.